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Dispossessed by decarbonisation: Reducing vulnerability, injustice, and inequality in the lived experience of low-carbon pathways

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ABSTRACT

This study examines the justice and equity implications of four low-carbon transitions, and it reveals the "lived experiences" of decarbonisation as manifested across Africa and Europe. Based on extensive, original mixed methods empirical research – including expert interviews, focus groups, internet forums, community interviews, and extended site visits and naturalistic observation – it asks: How are four specific decarbonisation pathways linked to negative impacts within specific communities? Relatedly, what vulnerabilities do these transitions exacerbate in these communities? Lastly, how can such vulnerabilities be better addressed with policy? The paper documents a troublesome cohabitation between French wineries and nuclear power, the negative effects on labor groups and workers in Eastern Germany by a transition to solar energy, the stark embodied externalities in electronic waste (e-waste) flows from smart meters accumulating in Ghana, and the precarious exploitation of children involved in cobalt mining for electric vehicle batteries in the Democratic Republic of the Congo. The aims and objectives of the study are threefold: (1) to showcase how four very different vulnerable communities have been affected by the negative impacts of decarbonisation; (2) to reveal tensions and tradeoffs between European transitions and local and global justice concerns; and (3) to inform energy and climate policy. In identifying these objectives, our goal is not to stop or slow down all low-carbon transitions. Rather, the study suggests that the research and policy communities ought to account for, and seek to minimize, a broader range of social and environmental sustainability risks. Sustainability transitions and decarbonisation pathways must become more egalitarian, fair, and just.

1. Introduction

The Paris climate accords aim to keep global temperature rise well below 2 °C,[1 aspiring to stay below 1.5 °C above preindustrial levels on a path of "deep decarbonization" (Rockström, 2017; Moberg et al., 2019; Geels, et al., 2017). Reaching either one of these goals requires a rapid transition towards low-carbon energy and mobility systems by 2050 ([IPCC] Intergovernmental Panel on, 2019; Hansen, et al., 2017).

Western Europe-inclusive of the European Union (EU) but also countries such as Norway-has long been viewed as a forerunner in implementing progressive energy and climate policies, and accelerating emissions reductions necessary to reach a 1.5 °C target. As the European Commission described itself when justifying a vision for a climate neutral economy in 2018, "the EU has been at the forefront of addressing the root causes of climate change and strengthening a concerted global response in the framework of the Paris Agreement" (European Commission & Planet, 2018). For instance, the EU has already reduced its collective greenhouse gas emissions by 22% from 1990 levels, and is on track to reduce them by 26% below 1990 levels by 2020 (European Environment Agency, 2018). This is no small feat, considering that the EU-28 is responsible for 11.9% of total final energy consumption worldwide, coming after only China and the United States, and it is also responsible for 10.4% of global carbon dioxide emissions (Commission, 2019). Future projections and formal planning documents at the national and regional scale are aiming for a "zero-carbon" Nordic energy system (International Energy Agency and Nordic Energy Research., 2016), a "net zero" United Kingdom

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(Committee on Climate Change, 2019), and a "Climate Action Plan" to decarbonize Germany (German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety, 2016).

However, the political responses to climate change can become embroiled in economic displacement, unemployment, embodied externalities, and human rights abuses. The path towards decarbonization can bring social net benefits, but it can also enhance vulnerabilities. As Carley et al. write, "Some individuals and communities are more vulnerable to possible adverse impacts than others" (Carley et al., 2018). This makes it difficult for both policymakers and consumers to connect the abstract, complex, and nonlinear processes of climate change with efforts aimed at addressing vulnerability or equitably distributing the co-benefits of climate action (Markowitz & Shariff, 2012; Alberini et al., 2018; Balbus et al., November, 2014; Burke, 2018; Noel et al., 2018; Ürge-Vorsatz, 2014; Sovacool et al., 2020; Sovacool & Dworkin, 2014).

In this study, based on an extensive original qualitative dataset utilizing mixed methods across multiple countries, we ask: How are four specific European decarbonization pathways – nuclear power in France, solar energy in Germany, smart meters in Great Britain, and electric vehicles in Norway – linked to negative impacts within specific communities? Relatedly, what vulnerabilities can low-carbon transitions exacerbate in these communities? Lastly, what policy reforms need to be implemented?

Our analysis is centered on four qualitative case studies. These cases emerged from our first phase of research when we conducted interviews and focus groups in France, Germany, Norway, and the United Kingdom (UK). This led us to a second phase of extended field research in Southern France, Eastern Germany, central Ghana, and Southwestern Democratic Republic of the Congo (DRC). Based on these data, the paper documents and humanizes the troublesome cohabitation between French wineries and nuclear power, the negative effects from solar energy on labor groups and workers in Eastern Germany, the stark embodied externalities in electronic waste (e-waste) flows from smart meters accumulating in Ghana, and the precarious exploitation of children involved in cobalt mining for electric vehicle (EV) batteries in the DRC.

The aims and objectives of the study are threefold: to showcase how four very different vulnerable communities have been affected by the negative impacts of decarbonization; to reveal tensions and tradeoffs between European low-carbon transitions and local and global justice concerns; and to inform energy and climate policy. In identifying these objectives, our goal is not to stop or slow down all low-carbon transitions. Rather, the study suggests that the research and policy communities ought to account for, and seek to minimize, a broader range of social and environmental sustainability risks. Through a rich, mixed methods study, we make a contribution to the literatures on dispossession; political ecology, economy and geography of energy transitions; and the whole system and justice implications from energy transitions. Our study shows that decarbonization pathways must become more egalitarian, fair, and just, empowering communities and challenging, rather than strengthening, the power of energy, mining and waste corporations. Furthermore, the study is not only descriptive or diagnostic, it is also normative or prescriptive. It presents rich, original mixed methods data from our four cases, drawn from 48 expert interviews, on policy solutions. The article therefore moves beyond only identifying problems to more actionable recommendations planners and other stakeholders can leverage to combat injustice. This helps push the policymaking community towards more "justice aware" incentives and policy mixes, a critical "new frontier" for this type of research (Sovacool et al., 2017).

Our paper is arranged as follows. Section 2 discusses our conceptual approach and how we build on previous literature. We outline details of our cases and empirical data collection in Section 3. Results are presented in Sections 4–7, which we then discuss further in Section 8. Section 9 concludes with also recommendations for policy.

2. Conceptual connections: Dispossession, sacrifice zones, and whole-systems justice in low-carbon transitions

As an overarching conceptual framework to help guide our interpretation of results and connect it to ongoing debates, we engage with the notions of dispossession, political ecology, sacrifice zones, and energy justice.

First, to the literature on *dispossession*, we broaden and empirically confirm its presence across comparative cases (varying geographic context) as well as different low-carbon systems (varying technological specificity). Political dispossession has been defined as the (neoliberal) restructuring of the state by finance through the privatization of profits, and the socialization of losses (Keucheyan, 2018). Bernstein has also developed a typology of physical dispossession, or land-grabbing, that emphasizes pressures coming from political elites in urban areas or even transnational flows of capital (Bernstein, 2010). Dispossession can be associated with the processes that market elites utilize to effectively possess the assets of others (Sovacool et al., 2019). Our cases show how dispossession can also arise from economic factors (such as differences in wealth and income between elites and community actors) or environmental factors (such as toxic pollution). We return to these in the conclusion.

Second, to work emerging on the *political ecology*, political economy and geography of energy transitions, we reveal a host of injustices – a broader lexicon of vulnerability or exclusion—extending beyond where most literature focuses, which is land use, financing, or jobs and employment. Analyzing the political ecology and economy of decarbonization – its uneven power relations, conflicts, violence, elite interests and vulnerabilities – is crucial to more comprehensively understanding energy justice (Newell & Mulvaney, 2013; Swilling & Annecke, 2012). This illustrates the ways "in which uneven exposure to environmental benefits and harm is often not accidental and unintentional, but rather a product of a particular way of organizing production and its constitutive social relations" (Newekk & Mulvane 0000). Already in 2012, Zehner pointed to the range of ecological, social and economic costs of renewable energy systems and the prevalent focus on technological solutions at the cost of political and social change – productivism over reductionism (Zehner, 2012). Decarbonization strategies that do not challenge relations of power and sociocultural systems, political ecologists have illustrated, may simply displace ecological destruction and extractivism for industrial development and profits to more vulnerable communities.

The communities – often of color, indigenous peoples and poor people – who live in such ecological *sacrifice zones* are characterized by the way they are "required to make disproportionate health and economic sacrifices that more affluent people can avoid" (Lerner, 2010). These local and global inequalities have been linked to environmental racism (Bullard, 1993), the disproportionate effects on community of color both in the global North and the global South. Sacrifice zones not only denote infamous sites of fossil fuel destruction, such as sites of Mountaintop Removal in the United States (Fox, 1999), but have become part of the green economy and its decarbonization efforts (Scott & Smith, 2017). Scott and Smith have shown how solar energy systems might clash with arable land and food justice concerns (Scott & Smith, 2017), and Hernández illustrates how "energy sacrifice zones" link vulnerable communities along the lifecycle of renewable energy technologies (Hernández, 2015).

The final area of intellectual engagement relates to *energy justice*. Building on earlier critiques of the injustices associated with climate mitigation measures (Roht-Arriaza, 2010), scholars have illustrated the processes of exclusion, inequality, marginalization or even the repression and criminalization of resistance against decarbonization strategies in the broad domain of energy and climate policy. These include the procedural injustices, the unequal social and ecological impacts and uneven benefits of wind farm permitting and siting (Dunlap, 2018a, 2017, 2018b), or the exclusionary nature of land decision-making for biofuel (German et al., 2011; Borras et al., 2010) or tree plantations (Baka, 2017), and even large-scale solar energy (Yenneti et al., 2016). Others discuss elitism or unfairness in energy and climate financing (Sovacool et al., 2019) or policy and program design (Baker et al., 0000; Baker, 2015). A related stream of work emphasizes "just transitions" and the actors or institutions that have the most to lose (in terms of jobs, assets, or credibility) as societies around the world decarbonize (Newell & Mulvaney, 2013). In addition to socially "just", however, this paper also points to the need for decarbonization to be "environmentally just" (Newell & Mulvaney, 2013), i.e. not exacerbating or reproducing environmental inequalities, such as exposure to pollution, land degradation, contamination, toxic soils and heavy industry. We thus fortify this collection of research by revealing vulnerabilities and injustices in other areas of the supply chain or lifecycle of low-carbon technologies, especially manufacturing (for solar energy in Germany), material inputs (cobalt mining in the DRC), and e-waste flows (electronic waste scrapyards in Ghana). This offers more of a "whole systems" or "multi-scalar" investigation of energy justice (Sovacool et al., 2019).

3. Research methods: Case selection and mixed-methods research design

To better understand the justice implications of European decarbonization pathways and low-carbon transitions, we first selected national case studies. We identified four case studies where decarbonization has clearly occurred across two supply oriented (nuclear power, solar energy) and two demand/end-use oriented (electric vehicles, smart meters) dimensions. Our research design then centered on an initial phase of expert interviews, focus groups, and internet forums in France, Germany, Great Britain and Norway, followed by a second phase of deeper and targeted expert interviews, community interviews, and site visits in the Rhône Valley (Southern France), Bitterfeld-Wolfen (Eastern Germany), Agbogbloshie (Ghana), and the Katanga region (DRC).

3.1. Case selection

In terms of our case study selection, France is well known for being a major nuclear power producer, generating about three-quarters of its electricity from nuclear fission. Germany leads the world in its total installed capacity of solar panels per household. Great Britain's smart meter rollout has so far surpassed 15 million meter installations and is expected to reach 85% of homes or small businesses by the end of 2024, totaling 53 million meters. Norway is the world leader for the per capita deployment of battery electric vehicles, or EVs, where the country has the highest market share of electric vehicles anywhere in the world, surpassing 40% of new car sales in 2017, rising to 56% in 2019.

The formal methodological literature refers to this type of research design as a qualitative cross case comparison (Gerring, 2005), the idea being that comparative cases offer more generalizable findings than from a single case. Furthermore, for each case, we see heterogeneity in terms of different stages regarding when transitions begun, with France providing the most historical case with their civil nuclear program kicked-off after World War II and accelerating under the *Messmer Plan* in the 1970s, Norway introducing EV policies in the 1990s, Germany implementing its feed-in-tariff for solar energy via the *Energiewende* in the 2000s, and Britain entering the main phase for smart meters in the 2010s.

3.2. Phase One: Expert interviews, focus groups, and internet forums

Following case selection, we proceeded with a two-phase, or sequential, mixed methods research process. The first phase involved 64 expert interviews in the summer and fall of 2018 with a mix of respondents from academia, civil society, industry, and government, summarized in Table 1, in each of the four countries. In each interview, we asked (among other questions): What do you see as some of the most significant injustices or disadvantages to the energy transition being examined? We complemented data collection with focus groups and the monitoring of internet forums, both open to the general public. We conducted five focus groups in non-capital areas of each country, namely Lewes (Great Britain), Colmar (France), Freiburg (Germany, two focus groups), and Stavanger (Norway), asking the same semi-structured questions. We lastly posted research questions on online internet forums, three per country, to solicit public input beyond the focus groups. These internet forums had more than 2 million collective members and resulted in 58 additional responses, meaning they were open to a large block of possible respondents and helped hedge against the possible bias in our expert interviews and limited location of focus groups.

3.3. Phase Two: Focused expert interviews, community interviews, and site visits

This first phase of the research process generated a comprehensive and dispiriting list of 120 perceived injustices, across these four transitions, including 19 commonly recurring injustices. Analytically, such a long list of injustices fell across very different dimensions of justice, including distributive justice (costs and benefits), procedural justice (due process), cosmopolitan justice (global externalities), and recognition justice (vulnerable groups) (Sovacool et al., 2019). Nonetheless, this "list" of injustices did not weight the injustices by importance, nor did it seek to examine which particular communities may have been most impacted by a given transition. Some of the qualitative data, however, did strongly suggest particularly vulnerable groups (Sovacool et al., 2019).

For instance, respondents in France noted how wine growers and vineyards have been negatively affected by nuclear power development, with direct negative impacts such as changes to micro-climate and water quality, and indirect impacts such as reputational damage over nuclear accidents and leaks.

Respondents in Germany discussed how solar employees themselves were acutely vulnerable to the boom and bust cycles in the solar industry, with many losing their jobs and pensions, and entire communities (mostly in Eastern Germany) collapsing.

Respondents in Norway discussed scarce material inputs such as cobalt and terrible working conditions at places such as the DRC, and that cars were only deemed sustainable in Norway because they made the batteries for them somewhere else. The DRC currently dominates the global production of cobalt, with 69% of worldwide raw material production in 2018 (Moores, et al., 2019); the next largest producer is Cuba which accounts for only 5% of global production (Geological Survey, 2019). Industry analysts predict that DRC dominance will only grow in the future, anticipating that the country's share of cobalt production will rise to 75% by 2021 (Moores, 2018). This cobalt is an essential component of the standard batteries used for EVs which often consist of nickel–cobalt-manganese or lithium-cobalt-oxide designs.

Table 1
Overview of semi-structured expert research interviews, focus groups, and internet forums in Phase One of the Innopaths research project.

Method	Country	Date	Respondents	Illustrative institutions
Research interviews	*France*	July 2018	16 (mix of academic, government, private sector, civil society, and think tank respondents)	CEA (Atomic Energy Commission of France), Electricité de France, ESSEC Business School, Greenpeace, International Energy Agency, Organization of Economic, Cooperation and Development, WISE-PARIS
	Germany	July 2018	16 (mix of academic, government, private sector, civil society, and think tank respondents)	BMWi (Federal Ministry for Economic Affairs and Energy), Ecologic Institute, Fraunhofer Institute for Solar Energy Systems ISE, German Solar Association (BSW-Solar), the German Solar Energy Society (DGS), Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)
	Great Britain	August 2018	16 (mix of academic, government, private sector, civil society, and think tank respondents)	Department for Business Energy & Industrial Strategy, Citizens Advice, Energy Saving Trust, Good Energy, Oxford University, Smart Energy GB, University College London
	Norway	June – September 2018	16 (mix of academic, government, private sector, civil society, and think tank respondents)	Energi Norge, Ministry of Transport and Communications, NTNU (Norwegian University of Science and Technology), Statnett, the Norwegian Electric Vehicle Association (NEVA), TOI (The Institute of Transport Economics)
Focus groups	*France*	August 2018	3 (mix of genders, ages, and incomes)	–
	*Germany**	August 2018	4 (mix of genders, ages, and incomes)	–
	Great Britain	August 2018	2 (two older women)	–
	Norway	August 2018	6 (mix of genders, ages, and incomes)	–
Internet forums	*France*	September-October 2018	11	Que Choisir, Forum photovoltaique, Droit Finances
	Germany	September-October 2018	2	Photovoltaik forum.com, Solarstrom-forum.de, Building Technology Forum – Solar Energy
	Great Britain	September-October 2018	39	Money Saving Expert, Navitron, OVO Energy
	Norway	September-October 2018	6	Elbilforum.no, Tesla motors club Norway, SpeakEV

Source: Authors *Across two focus groups.

Batteries for EVs also surpassed batteries for mobile phones as the largest demand for cobalt in 2017 (Moores, 2018). Tsurukawa et al. calculated that the average EV involves 104 min of artisanal Congolese cobalt mining labor (Tsurukawa et al., November 2011).

In Great Britain, respondents discussed the massive waste flows being generated by smart meters, in-home displays, and associated materials such as batteries and cables, which often end up in African countries such as Ghana. Ghana and Agbogbloshie were chosen because of their high-volumes of e-waste, which is mostly imported from Europe (Schluep & Cambridge, 2012). Nearly *half* of all e-waste from the UK (approximately 17,700 tons) for instance ends up at a single scrapyard near Accra in Ghana called Agbogbloshie (Siegle, 2017; Hickey, 2018). On the receiving end, this amounts to roughly 250 shipping containers of e-waste from the UK arriving at Agbogbloshie every month (Ghana, 2018). The United Kingdom was also called out as the "worst offender in Europe" for illegal exports of e-waste, which also often end up in Ghana (Laville, 2019).

Therefore, our first phase of research was followed by phase two, where we focused on southern France (wineries and vineyards in the Lower Rhône Valley), Eastern Germany (solar manufacturing sites in Bitterfeld), Ghana (e-waste scrapyards at Agbogbloshie), and the DRC (artisanal and industrial cobalt mines in the Katanga Copperbelt) (see Fig. 1).

The objective was not necessarily to select cases that maximize representativeness (as in large N studies, with or without random selection) or present directly comparable features (*e.g.* as in cross-country comparisons) but to maximize the information content of cases, and to support exploration of various facets of a phenomenon. As such, our cases bring together different features of information-oriented case studies in the context of our focus on vulnerabilities linked to energy transitions (for which unexpected or inviable tensions are of importance), including:

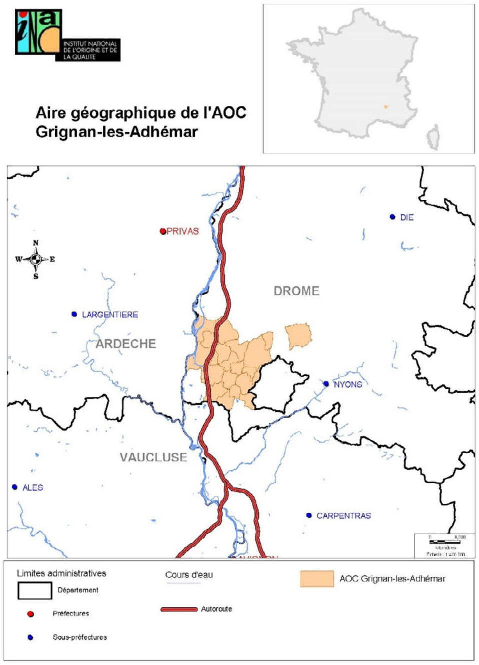
- "Critical cases" (Ghana and DRC as highlighting unquantifiable and acute levels of vulnerability). These cases are also "paradigmatic" namely as the extreme invisibility of a) concerned populations and b) up- and downstream impacts of energy transitions in the West;
- "Extreme or deviant cases" (France, Germany) as the vulnerabilities exposed are counterintuitive, especially given that the concerned communities initially benefitted from projects;

Together, the four cases also present "maximum variation" features as they offer opportunities "to obtain information about the significance of various circumstances for case process and outcome" (Flyvbjerg, 2006).

With these four vulnerable groups in mind, we embarked on our second phase of more focused research to collect data from them. As Table 2 summarizes, this involved 48 additional expert research interviews, 82 community interviews (with winegrowers and wineries, solar workers and community mayors, e-waste workers and their families, artisanal and industrial cobalt miners), and 69 site visits (including vineyards and cellars, solar manufacturing sites and communities, e-waste scrapyards and recycling centers, and cobalt and copper mines). To protect the identity of our respondents, we refer to these only generically by type (*e.g.* whether it was an expert respondent or a community respondent).

During each expert and community interview, respondents were asked: "What benefits and costs associated with nuclear power, solar energy, e-waste, or mining did you witness with the community?" "Who has been the most vulnerable, or significantly impacted?" "What community responses have taken place?" "What policies need implemented?" "What do you see the future as being like for affected communities?" Each interview lasted generally between 45 and 120 min (for the expert interviews) or 10 and 45 min (for the community interviews). Each of the naturalistic site visits lasted between 20 and 180 min.

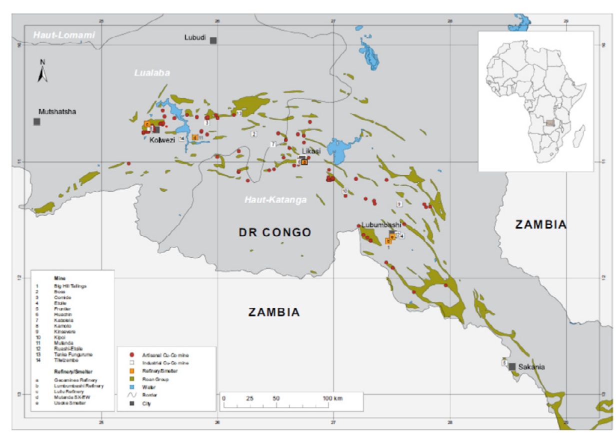
a. *French wine Appellations in the lower Rhône Valley (AOC Grignan-les-Adhémar)*



b. *The Bitterfeld community in Eastern Germany*

c. *The Agbogbloshie scrapyard for electronic waste near Accra, Ghana*

d. *The Central African Copperbelt and cobalt mines in the Democratic Republic of the Congo*



Source: Authors compilation.

Fig. 1. Vulnerable case study communities in France, Germany, Ghana, and the Democratic Republic of the Congo.

Respondents were guaranteed full anonymity to encourage candor and protect them from potential retaliation. All interviews were fully transcribed and coded, and each respondent was given a unique respondent number. For all community interviews and site visits, the authors travelled at all times with a team that included at least one native speaker (who spoke French, German, English in Ghana, or French and Congolese in the DRC). In Ghana and the DRC, this included a team of local research assistants who also spoke local languages such as Akan and Mole-Dagbani (in Ghana) and French, Kikongo, Lingala, Swahili and Tshiluba (in the DRC).

These methods together resulted in the collection of a rich, unique qualitative dataset that extensively documented the costs and risks to decarbonization across the four communities examined. The next Sections 3–6 present our results, and we make conclusions for both policy (drawn from a subsample of our expert interviews) and research in Sections 7 and 8.

4. Polluted vineyards and lost revenues: French wineries in the shadow of nuclear power

Our first case of nuclear power involves a state-backed energy transition championed by longstanding notions to make France "radiant" (Hecht, 1998) again but also to reinvigorate technical expertise in engineering as well as legitimacy with centralized state planning (Jasper, 1992). While there have been many vulnerable groups exposed to the externalities of nuclear power (such as negative learning and construction costs, water pollution and nuclear waste) in France (Chateauraynaud & Debaz, 2017; Brouard & Guinaudeau, 2015; Grubler, 2010; Topçu, 2008), we focus on a particular under-acknowledged group whose close proximity to nuclear power plants has been significantly impacted: French wineries, winegrowers and winemakers.

Table 2
Overview of semi-structured expert research interviews, community interviews, and site visits in Phase Two of the Innopaths research project.

Method	Community	Date	Respondents	Illustrative Institutions or Locations
Expert research interviews	*French wine*	January to February 2019	1–7 (mix of wine representatives, wine trade experts, wine specialists, anti-nuclear associations)	Commercial representatives of wineries, Syndicat général des Côtes du Rhône, Université du Vin, Wine trade experts, Wine journalists, Sortir du Nucléaire, CRIIRAD
	German solar	February and March 2019	1–7 (mix of research institutes, private solar firms, mayoral offices, unions)	Fraunhofer ISF, municipalities, mayoral offices, private solar firms
	Ghanaian e-waste	January and February 2019	1–11 (mix of government, civil society, private sector, and academic respondents)	Environment Protection Agency (EPA), Ministry of Environment, Science, Technology and Innovation (MESTI), World Resources Forum, Greater Accra Scrap Dealers Association (GASDA), Scrap Dealers Association at Agbogbloshie, University of Ghana
	Congolese cobalt mining	February to April 2019	1–23 (mix of government, civil society, private sector, and academic respondents)	Service d'Assistance et d'Encadrement du Small Scale Mining (SAESSCAM, recently renamed SAEMAPE, the Ministry of Mines, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Gécamines (state-owned mining company), 'entreprise minière Congo Dongfang Mining (CDM mining), Tenke Fungurume Mining (TFM), Glencore, and Ruashi Mining, Université de Kinshasa, Université de Lubumbashi
Community research interviews	*French wine*	January to February 2019	1–6 (winegrowers and residents)	Various local winegrowers, wineries, and bottlers in the Rhone and Grignan-les Adhémar regions
	German solar	February and March 2019	1–7 (local community members, ex-solar workers, local journalists)	Ex-solar workers in the Bitterfeld region, other local affected community members
	Ghanaian e-waste	January and February 2019	1–21 (e-waste scrapyard workers, their families, labor leaders, politicians, and those supporting e-waste via marketing and vending)	E-waste workers and communities throughout Agbogbloshie and the greater Accra area
	Congolese cobalt mining	February to April 2019	1–48 (mix of artisanal cobalt miners as well as artisanal bosses or chiefs, crushers, carriers, drivers, refiners, safety inspectors, sorters, labor unions and members of the mining police)	Various artisanal mining teams, artisanal mining communities and households across Kolwezi, Likasi, Fungerume, and Lubumbashi
Site visits and naturalistic observation	*French wine*	January to February 2019	7 vineyards (within and beyond focal AOC), wine cellars, winemaking training centers and archives, 3 nuclear sites, and 1 Wine Trade fair in Paris	Within AOCs Grignan-les Adhémar, Côtes du Rhône, Marcoule, Tricastin, Cruas-Meysse
	German solar	February and March 2019	8 (solar manufacturing sites, affected communities, administrative decision-making centers)	Solar Valley, Bitterfeld-Wolfen, Halle, Magdeburg
	Ghanaian e-waste	January and February 2019	20 (formal and informal scrapyards, affiliated industries)	Agbogbloshie scrapyard, Old Fadama Market, Agbogbloshie Health Clinic, Accra Compost & Recycling Plant, Akooshi Recycling Centre, Dawa Steel Mill and Export Zone, various electrical shops
	Congolese cobalt mining	February to April 2019	30 (artisanal and industrial mines, legal and illegal mines, mines as well as trading depots and processing centers)	Ruashi artisanal cobalt mine, Kasulu artisanal mine, Depot 169, Depot 2, Depot 18, Depot 1000, Depot Thomas Boss Billy, Solola and Kabica artisanal mines, Katanga and Fungerume artisanal mines, Kawama artisanal mine

Source: Authors. AOC = Appellation d'Origine Contrôlée.

During our first round of interviews and focus groups in France (See Appendix I for more details on methods), respondents noted that nuclear plants had impacted negatively on some agricultural sectors, notably wine making, with one expert respondent noting that winegrowers in particular were "*very resistant to nuclear development*." This point was also picked up by another expert respondent who claimed that "*wine growers* ... *whose vineyards were in the vicinity of plants were affected. In other areas* ... *there is radioactive material in the water supply*."

Given that nuclear power generation activities are sited near water sources for cooling purposes, a significant number of France's 58 nuclear reactors are located in the vicinity of French winegrowing areas. We thus focused on the cohabitation of wine and nuclear industries in the lower Rhône valley – a significant winegrowing region, and also one of France's "most nuclearized" areas (Roudil, 2007). We focused in particular on the area around the 3660 MW Tricastin nuclear power site which hosts four reactors, fuel processing, enrichment and storage activities, and employs an estimated 8000 people (Rhône-Alpes, 2012).

Across the river from the Tricastin nuclear facility, the Appellation d'Origine Contrôlée (AOC) Côteaux du Tricastin ("protected designation of origin" certified by the Institut national de l'origine et de la qualité, or INAO), obtained its certification in 1973. (Olivier, 1996) Since the mid-1980s a series of incidents at the nuclear site have exposed the vulnerability of safety measures, worrying residents, and, most critically, affecting the image of local agricultural produce including wine. For example, in April 1987, Areva's Tricastin fast breeder reactor leaked coolant, sodium, and uranium hexachloride, injuring seven workers and contaminating water supplies (Sovacool, 2011). This incident was one of a string of failings in the late 1980s, taking place in the wake of the 1986 Chernobyl disaster and contributing to "deteriorating the image of the nuclear industry in France" (Roudil, 2007).

Further safety concerns followed, and since 1997 the government has organized the distribution of iodine tablets to residents living in the immediate vicinity of nuclear sites in case of major incident (CSN, 2001). As one community respondent recalls:

Tablets were distributed to residents of certain municipalities, while others were decided out of the perimeter, which was quite worrying as if a tablet would be the thing to save us in case of a nuclear disaster ... There is an unusual number of people who developed unexplained cancers.

In 1999, a number of safety failings took place on the Tricastin site, including the irradiation of a worker in a "red zone." This led the Direction de la Sûreté des Installations Nucléaires (DSIN) to heavily criticize Électricité de France for failing to meet routine safety standards (LM, 1999). In another accident in July 2008, radioactive wastewater was released into local rivers, leading to the closure of the entire nuclear site, a ban on irrigation, and the local population having to rely on bottled water (LM, 2008a, 2008b). The incident, even though it was classified as "minor", became a truly "runaway media event", and its effects were not contained even by a concerted Public Relations strategy (Suchet, 2015). An expert respondent recalls that if previous, less mediatized, incidents had not significantly affected the wine industry, the 2008 crisis led winemakers to "*change position ... they were no longer willing to remain associated to nuclear*".

Indeed, these accidents at Tricastin almost instantly tarnished the image, reputation and attractiveness of the local wine production, which has struggled to recover especially since the 2008 events. Production dropped by 40% over the 2 following years, with one expert respondent confirming that "*many owners opt[ed] to uproot their unproductive vineyards*" (AFP, 2010). Reacting to the incident, a representative for Inter-Rhône (the Interprofessional association of Rhône wines) commented that it would be "pointless" to try and sell a bottle of Côteaux du Tricastin, as they would be "laughed at" (LE, 2008).

Community respondents told us that loyal customers and restaurateurs (including reputable chefs) started fleeing the appellation that had become perceived as toxic and unsellable, leading the AOC to commission a survey to better understand consumer sentiment. One respondent noted that "*we made the mistake of believing that this cohabitation with nuclear energy would be profitable*." The incidents in the 2000s especially occurred at a particularly difficult time for the AOC, having halved its production between 2002 and 2007 (LE, 2008). They are akin to an environmental form of dispossession, where perceived pollution flows (visible and invisible, such as radioactivity) interlink with preexisting economic or geographic factors to marginalize one community (winemakers) over another (nuclear suppliers).

5. Sacrifice zones: The dispossession of German solar energy workers

Our second case focuses on Germany, known for its community-backed, more democratically planned push for low-carbon yet distributed electricity sources, especially household solar energy (Morris & Jungjohann, 2016). Since the 1990s, Germany has sought to catalyze low-carbon industrial sectors, including solar photovoltaics (PV) and wind, stimulating these through the *Energiewende's* feed-in tariff as well as the provision of investment grants for example in the eastern states of Germany (Fraunhofer, 2018). However, during our first round of interviews and focus groups in Germany, respondents cautioned that the solar transition was only of temporary benefit to some of its workers. As one expert respondent explained:

The real vulnerable group from the solar transition is not often talked about, namely 100,000 people who lost their jobs in the German solar sector over the past years. You have trade unions and government going, oh my goodness, we cannot shut down coal because of all the work and these regions. Yet Solar World and other big producers have shut down in the past years and they didn't make a peep about those workers. Workers in the German renewable energy sector are a vulnerable population.

The Eastern German region of Bitterfeld-Wolfen, Saxony – a former coal mining site and now a self-proclaimed green-industrial city – was both central to solar PV manufacturing and particularly effected by its boom and bust cycles (Brock et al., forthcoming). Since 2008, the market share of German solar manufacturing has dropped dramatically. Unable to compete with subsidized Chinese production, an estimated 90% of German solar jobs have been lost and almost every major solar manufacturer has filed for bankruptcy (Lütkenhorst & Pegels, 2014). The International Renewable Energy Agency estimates that solar jobs in Germany reached a high of more than 100,000 employees in 2008 dropping to fewer than 36,000 by 2018 ([IRENA] International Renewable Energy Agency, 2018).

The fall of the solar sector had several key negative impacts for Bitterfeld-Wolfen. Around 5000 direct jobs in solar manufacturing were lost in the region. Although some of those in white collar managerial jobs were more mobile and could move elsewhere, lower skilled workers, who had been trained in the sector and were not unionized, had to seek new jobs. These were often found within the region's chemical parks or the newly-opened car factories near Leipzig, for example, though many remained unemployed. The impacts thus hit lower-skilled workers hardest, causing political resignation, rising class inequalities and lack of opportunities particularly for low-skilled workers. This illustrates, once again, that "green" jobs are not automatically "good", well-paid, secure or well-protected against market dynamics.

Local communities and municipalities also lost out in several ways. They forwent the high tax revenues they had been enjoying for several years, with many of the local amenities such as recreation centers, swimming pools, and schools that had been sustained by solar wealth now lying dormant. Furthermore, some municipalities which had entered into cost-sharing arrangements with private solar companies on industrial parks for example were left with debts to pay, and no private sector counterpart to share the costs. As one community respondent said:

A disadvantage for the community was that they were stakeholders in the businesses in solar valley and were co-owners of the water, security, road, waste water, street lamps, road gritting infrastructure, especially in Thalheim village. They not only lost revenues on lost profits that they had been enjoying but also had to bear some costs of site decommissioning, e.g. paying for security systems to be de-installed.

This created a double burden of not only lost jobs and income, but additional costs for decommissioning.

The bust of the solar industry essentially transformed Bitterfield-Wolfen, once again. This transformation must be read in the context of the past experience of collapse after the end of the coal industry and the fall of the Berlin Wall in 1989, which had economically and socially disastrous effects on the area – including job losses, young people leaving the area, deprivation and poverty. The psychological impacts, depression and political resignation following the fall of the solar manufacturing thus brought back bitterness and feelings of acting as a "*sacrifice zone*", according to one community participant, for 'German' industrial development – first to provide coal-powered electricity to rebuild Germany after the war, and now for the broader renewable energy transition. "*Berlin got the electricity, we got the ashes,*" the interviewee added. As another community respondent explained, "*Everything was moving very fast and then suddenly... the catching up* *was over*." The fall of solar meant that many "*families were hit twice*", as a local respondent explained, and the new pride about having an international corporation – the biggest one in Eastern Germany – was quickly crushed, followed by disillusion.

Both expert and community respondents showed mixed feelings about what some saw as the "inevitability" of the effects of free markets searching for the most profitable places for production, while others pointed to the role of the German government in letting the industry "fall": the refusal to provide subsidies in the face of subsidized Chinese competition or to impose tariffs onto foreign panels out of concerns for the German automobile industry (Brock, et al., forthcoming). As one expert explained: "*The government* could *have tried to give subsidies to the industry as it does with other sectors, such as the automobile industry, but it didn't want to*". The German case was thus strongly shaped by shifts in government policy – unemployment in the solar energy sector was seen as an acceptable loss politically compared to efforts to protect the (historically socially embedded and strongly unionized) coal sector – coupled with intensified competition from Chinese firms, rather than a saturated market. The end result was political resignation, depression and cynicism that facilitated the rise of anti-migrant populism and the far right (Lobenstein, 2017) in the area.

6. Embodied externalities: The toxic effects of smart meters, batteries, and e-waste in Ghana

Our third case involves a more complex geopolitical and neocolonial relationship between Ghana, a former British colony, and burgeoning flows of hazardous e-waste emanating from Great Britain (and elsewhere in the Global North) (Amankwaa, 2017; Amuzu, 2018). During the first round of our data collection in Great Britain, respondents discussed the generation of e-waste flows and recycling challenges that emerge from the smart meter rollout. This relates not only to the old meters that smart meters are replacing, but the smart meters themselves, which were estimated to have a much shorter lifetime of 5–10 years compared to average 50–60 years of a typical old meter. Other respondents discussed the waste flows with smart meter associated in-home displays and batteries. As one expert respondent stated, "*If you think of the in-home display and environmental impact, it's another digital device in people's homes, another thing that they don't necessarily need that will be eventually recycled, managed and wasted*." Smart meters thus contribute to a growing wave of accumulated electronic devices that generate streams of e-waste.

The majority of e-waste that the UK exports, including those for in-home displays, monitors, cables, computers, and batteries, ends up at Agbogbloshie in Ghana. Agbogbloshie is a community neighborhood and scrapyard, formerly a wetland, within the Greater Accra Metropolitan Area. Even though it is relatively small-less than a square mile in total size – it is the "main hub" in the country for e-waste, home to at least 40,000 inhabitants living and working around the scrapyard (Akortia, 2017). Agbogbloshie is also closely located to local communities and the cohabitation of the scrapyard alongside a yam market, tomato market, onion market, football pitch, and mosque.

A convergence of factors makes the scrapyard an excessively toxic environment. Batteries from EVs and other devices are subject to uncontrolled acid drainage, as well as hazardous methods for breaking batteries with machetes (see Fig. 5). (Atiemo, 2016) Highly toxic elements reside within e-waste streams, including capacitors containing polychlorinated biphenyls, gas discharge lamps, batteries, plastics containing brominated flame retardants; liquid crystal displays, external electric cables and electrolyte capacitors as well as asbestos, mercury, refractory ceramic fibers, and radioactive substances ([Ghanaian] Environmental Protection Agency., 2018). Unlike organic waste, the hazardous materials involved in e-waste are longer lived and more potent, with exposure being chronic and constant (Itai, 2014). Multiple vectors exist for e-waste toxins to spread, including air, water, food, smoke, and dust (Akortia, 2017). Unlike most waste facilities in Europe or North America, residents live in close proximity to the pollution flows and open burning, which exposes not only male workers, but also women and children in those areas (Srigboh, 2016). Insufficient personal protective equipment are available for workers, and health and safety monitoring for workers and neighboring communities is absent (Atiemo, 2016).

One expert respondent contextualized the dilemma of e-waste processing in Ghana as follows, noting severe risks for e-waste workers, women and children:

> *E-waste, growing daily via the use of computers, batteries and other smart energy systems, has directly resulted in one of the biggest slums here in Ghana, the second biggest slum in Africa, one of the five biggest in the world. More than 100,000 people live here in abject poverty, home to the biggest dump for scrap metal and e-waste in the world. Young boys and girls, children as young as six, seven, and eight years old are engaged in this business. They miss school or end up dropping out of school, they go to the slum for a career, or they look for scrap to finance their own education. Even though they go to look for scrap metal, they end up doing it for the rest of their life. I know a story of a young boy, who was not wearing any protective clothing, who got so damaged by the hazardous material he died at the age of 12. Others see their life shortened by decades. They cough, get infected, and fall sick. They dedicate their youth to renting a wooden structure to sleep at night, 5–6 children in a shack, close to the metal business so they can work longer hours. They can make around $5 per day, some very good ones $8 per day, trying to get copper, aluminum, and wiring, to sell it to other agents. It becomes their life.*

Another community respondent agreed that "*e-waste activity affects bystanders as well, female vendors selling water, cooks and chefs, also farmers, traders, even shoppers at nearby markets*."

During the site visits, for example, children were playing football amidst the toxic dust and fumes; young boys from Benin were burning scrap; dozens of women and children were selling water and food (in the open air), one five year old child was carrying a circuit board; and one Iman was even leading a group of chickens across the scrapyard towards his mosque, pecking and eating toxic material along the way.

Our interviewees suggested that many scrapyard workers and households know of these risks, but simply accept them in the absence of other opportunities. One expert remarked that "*Agbogbloshie is a huge market for a population otherwise with no means of survival in the urban environment. These people, they are not stupid, they know the health risks, but they think: isn't dying slowly better than already dead*?" Another expert respondent noted that "*the health risks are severe among e-waste workers themselves, who are constantly exposed but have no personal protective equipment (PPE). The work they do is highly hazardous, but the absence of PPE, no gloves, no nose bands to protect them from smoke, living constantly in toxic fumes, is like living in a giant cigarette all the time. Yet getting sick is a death sentence. They will ignore symptoms and avoid hospitals*."

A final dimension to vulnerability relates to refugees and migrants who take up new jobs at the e-waste scrapyard. Migratory workers and new entrants to the site are given the worst jobs, and identified based on their religion or ethnicity. One community respondent stated that "*new e-waste workers are extremely exposed . . . when they arrive, they are placed at the bottom of the scrapyard hierarchy and are given the most toxic jobs, such as burning*." During the site visits, it was almost always a newer arrival from the Northern Provinces of Ghana, or immigrants from Benin and Togo, who were seen burning, never those from the Southern Provinces or longer-time residents of Agbogbloshie. Another community respondent suggested that "*some new arrivals collect scrap with babies on their back, sweating in the heat, other waste workers are mere children, such as boys from Benin who can be as young as 6 and 7 [years old], burning for copper*."

7. Child labor: Exploitation and violence in Congolese cobalt mining for electric vehicles

Our final case involves mining in the Democratic Republic of the Congo, a regime with a history of armed conflict, internal displacement, the militarization of natural resources and struggles over governance that have lasted at least three decades (Haider & Rohwerder, 2015). Mining in particular is associated with not only weak oversight and governance, but an inverted hierarchy of interests that place corporate firms, mining associations and the national government (and its security forces) above the actions of communities and the miners themselves (Katz-Lavigne, 2019; Vogel, 2018).

During our first round of data collection in Norway, multiple respondents discussed issues of mineral inputs, metals, and extractive industries needed to manufacture EVs. Respondents discussed how EVs are only "*green*" and "*clean*" in Norway because they are made somewhere else. As one expert respondent noted, "*There are things with battery production that are of concern. Scarce materials, terrible working conditions for people in mines in the Congo where they have to get cobalt from*." As another explained, these mining activities form the mineral backbone for low-carbon transitions involving batteries, especially for EVs. They stated:

Mining and extractive industries represent the spine or backbone of the industrial manufacturing sector that makes all of our low-carbon innovations and products. Without metals and minerals, these products simply wouldn't exist. The key to our low-carbon future is minerals, with very specific properties of materials with unique effects, so how we manage minerals will determine how society can function. The key will lie in better sustainable production and extraction. We see this need most clearly in the cobalt mines of the Congo, which feed currently into every available EV on the market.

Almost all of the DRC's cobalt resources are concentrated in one region, the "Copperbelt" or "geological scandal" of Katanga, which sits in the Southeast near the Zambian border, and contains an estimated 3.6 million tons of recoverable cobalt (World Bank, 2007). There, cobalt is commonly mined as a byproduct of either copper or nickel mining. This region of DRC has some of the highest quality reserves globally, which makes it especially suitable for artisanal and small-scale mining (ASM) efforts, where cobalt can be harvested with "low-tech" options including digging small tunnels by shovel, pickaxe, or even hand. ASM cobalt and copper mining in the DRC generally takes two forms. One is where miners, typically young men, work to dig underground tunnels with shovels, chisels, and mallets as far as 30–40 m deep. Another is where, some men and many children and women collect and dig for cobalt in discarded tailings and slurry close to – or even on – industrial large-scale mining sites and concessions. Both types of ASM have accelerated during the recent "cobalt rush."

Yet such mining activities, especially in the ASM sector, occur in a precarious working environment with little to no regard for safety or the protection of children. At ASM Congolese cobalt mines, the World Bank (World Bank, 2007) has noted, poverty is rampant, and the vast majority of miners are subsistence diggers (or *creuseurs*) that barely make enough to survive. Many are refugees fleeing regional ethnic conflicts and wars, or orphans. Child labor is widely used, with many orphans and ex-child soldiers seeking the livelihood opportunities offered by ASM cobalt mining, also due to a lack of incentives for school or other jobs. Gender discrimination is entrenched even though up to half the ASM workforce are women, with gender norms affording women lower status than men, leading to unfair practices (women get the worst jobs, for lower pay), obstacles to land ownership, illiteracy, and widespread sex work. Best practice techniques or equipment is completely lacking, with low levels of mechanization, poor recovery efficiency, poor ventilation and lighting, and crude mining techniques. Occupational health and safety is nonexistent, with frequent injuries, mine collapses and accidents, as well as chronic exposure to mercury, dust, fumes, rock falls, landslides, and other environmental risk factors. Environmental degradation is severe, with little regard for local environmental protection or ecosystems, with direct dumping of waste and tailings, effluents discharged into rivers and alluvial areas, soil erosion, deforestation, and the loss of biodiversity. When communities discover cobalt (or other mineral) resources of high value, they are often dispossessed by state or corporate actors from accessing them, i.e. refused licenses or permissions to mine, and in extreme cases forcibly relocated from those sites, as was the case with the eviction of "tens of thousands of people" near a £75 billion discovery of cobalt near Kolwezi (Baker, 2019).

These features culminate in a "*toxic environment*" for mining, one that an expert respondent put this way:

ASM cobalt mining is not living, it's dying. The moment you step inside the mine, the clock starts ticking. You are exposed to dust which can lead to silicosis, or be poisoned by mercury. You can drown, or become trapped in a mine collapse. You can get crushed by rocks, or even contract diseases by people shitting or urinating into the mine. You can suffer diseases from sitting in water all day, such as cholera or malaria, or get bitten by animals, as many miners will bring them into the mine. This is especially the case when they remain underground in deep shafts for 5 or even 7 days at a time – it's an underground circus at that point, full of animal and human excrement, I've even heard of people contracting the plague in such conditions. Here in the Congo, you have elevated risks for heavy metal poisoning from nickel or cobalt, or radioactivity poisoning from uranium. Even if such things cannot kill you, they can still dismember or injure or disable you. I know of people who lose arms or legs in a collapse, they have to painfully break their bones to pull free. Many then bleed to death in the jungle. Injury is often a death sentence, because you're usually on your own, far away from any medical attention. Whether quickly or slowly, make no mistake, ASM cobalt mining will kill you.

Another expert respondent agreed and noted the "*integrated nature of the threats*" that arise from cobalt mining, which lead to "*poor and polluted workers*" as well as "*severe negative impacts on local communities, including heavy metals in food and water, and extremely high levels of cobalt and copper in the blood and urine of women and children*." These can threaten miners with a host of direct effects related to the mining itself, as well as indirect effects that impact miners, their families, and local communities near mining sites, such as pollution or increased risk of birth defects (Van Brusselen, 2020).

The costs to ASM cobalt mining were not hyperbole, and were mentioned by the miners themselves the research team spoke with. One community respondent, a digger who stated to be fourteen, said that he "*work[s] 10 to 14 h a day, when there is daylight, so that I can send money to my sisters and my mother*." Another young miner told the authors he was an orphan and that he "*mines cobalt with a shovel to support three younger siblings*." Another community respondent said that "*We just jump in the hole, no safety. Fear is always there, so I am always scared inside the mine. We just have to conquer our fear*." Yet another remarked that "*most of us suffer from coughing, muscle aches, our body hurts all over. We work with-*

out protection so we breathe in the dust, it gives me a permanent flu." None of these young cobalt miners had protective shoes, gloves, trousers, respirators, or helmets, just a single lamp and some muddy clothing.

8. Policy implications and recommendations

These four cases imply that the global community needs a coordinated policy mix to reduce vulnerability across the dimensions of raw materials, planning and policy processes, adoption and use of low-carbon technologies, and waste management (see Fig. 2). Here, we tap into our collective 48 expert respondents and reflect on the recommendations they gave to our question about improving policy outcomes and making the four transitions more equitable and just. To give a bit more context as to how much this suggestion recurred across our interview data, we have put frequency counts to the side of each suggestion.

At the stage of raw materials, greater transparency and traceability about supply chains and sources would better reveal lifecycle externalities so that they could be accounted for. Adherence to the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals would better protect vulnerable groups, especially child miners in sub-Saharan Africa. Enforcement of occupational and community health guidelines would ensure many of the most toxic and safety risks associated with mining could be mitigated.

At the stage of planning and policy, the inclusion of more diverse groups of stakeholders would better recognize concerns related to gender or other demographic elements to transitions, including ethnic groups and indigenous populations. Adherence to meaningful Free Prior Informed Consent would both substantively increase the involvement of vulnerable groups and also enhance a social license to operate and legitimacy for each transition. Stronger Social and Environmental Impact Assessments, or Impact Benefit Agreements, would require by statute that local communities more directly benefit.

At the point of adoption, diffusion, use, or energy consumption, some experts suggested that the promotion of shared ownership and new business models (such as mobility as a service, or peer-to-peer trading) could expand the access of low-carbon innovations to reach previously excluded groups, although the literature suggests that such interventions can also be problematic and involve trade-offs across different dimensions of justice (Sovacool et al., 2019). Multiple respondents suggested that compensation or retraining those whose livelihoods have been disrupted would better meet calls for a just transition. Strengthening consumer protections, especially for privacy, data, and regressive effects, would also increase public confidence and establish legitimacy.

Lastly, at the point of waste management, transparency and traceability about supply chains and sources would (similarly to raw materials) better reveal and account for externalities. Expansion of Extended Producer Responsibility would minimize waste flows and increase the recyclability of low-carbon innovations. Expanded legal sanctions and higher and enforced fines would also minimize illegal shipments of e-waste, and ensure waste flows are better governed.

9. Conclusion and implications

Four European low-carbon transitions – French nuclear power, German solar energy, smart meters in Great Britain, and Norwegian electric vehicles – have sobering and troubling connections to economic dislocation, unemployment and poverty, toxic externalities associated with e-waste, and the exploitation of women and children in cobalt mining, as Fig. 3 illustrates.

Borrowing from the literature and logic of dispossession and sacrifice zones, they can result in or perpetuate environmental dispossession (radioactive pollution or toxic exposure that degrade land or assets), political dispossession (unfair and exclusionary modes of policymaking and planning), economic dispossession (lost jobs, eroded revenues, bankrupt businesses), and even physical dispossession (coercion and the constant threats of violence or force). Table 3 shows how environmental dispossession is present across all four cases, to varying degrees, alongside economic dispossession. Political and physical dispossession are less common, but still present in two of the cases. Examining the evidence by case and not degree of dispossession, we can see all four aspects

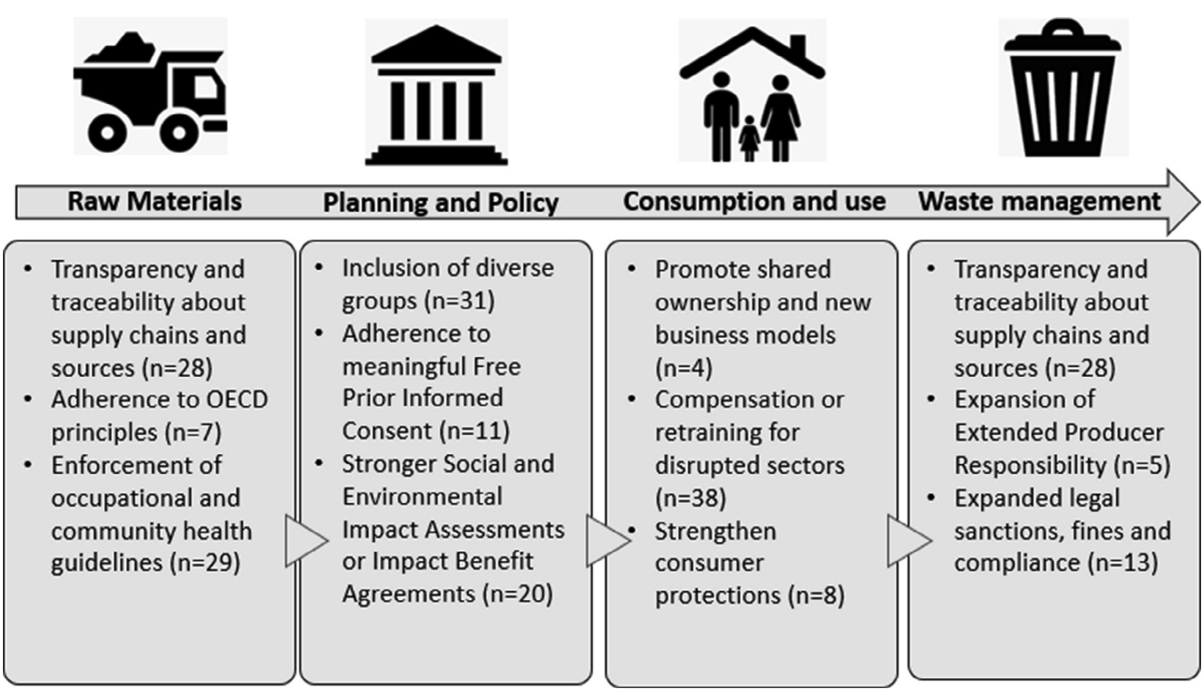


Fig. 2. A multi-scalar policy mix for reducing vulnerability to low-carbon transitions (n = 48 expert interviews).

a. Winegrowing in the vicinity of the Tricastin nuclear power plant across the Donzère-Mondragon canal from Bollène, France

b. Abandoned solar manufacturing infrastructure and factories at Solar Valley, Bitterfeld, Germany

c. Burning, draining, and sorting electronic waste at Agbogbloshie, Ghana

d. A young artisanal cobalt miner exiting in the Kawama mine near Lubumbashi, Democratic Republic of the Congo

Source: Authors. Express permission given by all communities and respondents for the photographs.

Fig. 3. Four vulnerable communities to European decarbonization.

Table 3
The multifaceted dynamics of dispossession across our four low-carbon transitions.

	Environmental, e.g. pollution and degradation	Political, e.g. unfair plans or procedures, lack of input in decision making	Economic, e.g. lost jobs, revenues, or community assets	Physical, e.g. coercion, violence, or discrimination
French wineries and nuclear power	+ (tritium concerns, nuclear waste)	+ (disputed safety regulations, secrecy surrounding accidents)	+ (lost revenues and reduced property prices)	
German workers and solar energy manufacturing	+ (occupational hazards)	+ (contested policy interventions)	+ (unemployment, bankruptcies, collapse of pensions and tax bases)	
Ghanaian electronic waste associated with smart meters and batteries	+ (waste burning, air and water pollution)		+ (monopolistic behavior informal enterprises)	+ (ethnic exclusion of some workers, beatings and frequent fights on the site)
Congolese cobalt mining for electric vehicles	+ (dust, pollution, and land use with mining)	+ (unfair nationalization of mining concessions, preference given to foreign firms)	+ (corruption and consolidation of mining royalties)	+ (dependence on child labor, exploitation of refugees and displaced persons)

Source: Authors.

of dispossession present in the Congolese case, but at least three forms present in *all* of the other three cases, implying that different forms of dispossession can aggregate or interrelate as they nest together in a nexus.

As Table 3 also implies, in some situations, low-carbon transitions affect non-vulnerable groups, and introduce *new* vulnerabilities through patterns of co-dependence raising exposure to reversals of fortune. For instance, French winegrowers historically benefitted from nearby nuclear power plants, and only became vulnerable to them after nuclear incidents attracted significant public visibility and spilled over into reputational and economic impacts. German solar factory workers received well-paying jobs and pensions until boom and bust cycles rendered solar manufacturing centers obsolete. In other situations, low-carbon transitions seem to aggravate and intensify *preexisting* vulnerabilities related to class, ethnicity, or age, with refugees and migrants in Ghana given the "worst" jobs at Agbogbloshie, and orphaned children exploited by cobalt mining bosses. In Germany, the rapid fall of solar manufacturing enhanced the pre-existing deprivation, inequalities and psychological damage following the fall of the Berlin Wall and the collapse of the coal industry and, triggering not just unemployment but political resignation and the rise of the far-right.

Thus, low-carbon transitions can create, reflect *and* entrench injustices and inequalities. They can intensify preexisting divides between North and South, rich and poor, frontier and interior, but also introduce new ones related to innovation patterns, local pollution sinks, and volatile employment and economic growth trends for communities. Our cases challenge and muddle up the very distinction – or juxtaposition – of "clean" and "dirty" energy generation by pointing to the social and ecological costs, often outsourced and therewith "invisibilized" – for Northern consumers – to countries of the Global South. Patterns of inequality and their reproduction blur the exploitation of old vulnerabilities with the perpetuation of new ones. While these issues are well known to scholars of globalization, development, and geography, we call for greater attention to the ways these structural patterns of injustice and inequality intersect with emerging low-carbon transformations in the name of sustainability. It is important here, and in other low-carbon transitions, to perpetually ask "sustainable for whom?"

One core conclusion resulting from this work is that we must resist the temptation to only examine low-carbon transitions (and the particular innovations underpinning them) at the point of use. We should also look beyond the demographic of beneficiaries and adopters in Europe. Instead, we must acknowledge the full spectrum of winners and losers, across lifecycle stages (extractive industries, manufacturing, end of life), spatial scales (extending to countries beyond Europe), and types of vulnerability (economic, environmental, and sociocultural). This would help fight the glaring disconnection between the low-carbon innovations prioritized in energy and climate policy discussions, and the serious impacts these innovations can have on vulnerable groups.

Relatedly, European low-carbon transitions are not just about Europe. They generate complex externalities across their entire lifecycle or whole system that reach as far as the artisanal cobalt mines of the DRC and the e-waste scrapyards of Ghana. Our study therefore challenges the nation state-centered way most planners craft national and international climate policy, focused on things like Nationally Determined Contributions under the Paris Agreement and national carbon footprints or emissions trajectories. We show its multi-scalar, within and beyond countries and involving the disparate stages of raw materials, planning and policy, adoption and use, and waste management, which challenges an entire regime of nationally oriented policymaking.

Furthermore, low-carbon transitions are not just about climate change mitigation. They become intertwined with preceding power dynamics and inequalities that can worsen patterns of prejudice and marginalization. The unintended or invisible impacts of low-carbon transitions can consequently tarnish the reputation and sales of agricultural enterprises, such as vineyards, operating in close proximity to nuclear infrastructure in France. Low-carbon transitions can create sacrifice zones of intensified unemployment and community disempowerment, such as the bankrupt solar manufacturing facilities in Germany, where they infest a particular locality with tangible direct and indirect benefits that can overshadow ensuing risks. Low-carbon transitions can externalize the dirty and toxic e-waste streams associated with smart energy systems from Great Britain to the scrapyards of Ghana. Low-carbon transitions can entrench and benefit from the exploitation of orphaned refugee children mining for cobalt needed to make EV batteries more affordable.

These often-obscured and rarely discussed dimensions to low-carbon transitions reveal that the lived experiences of decarbonization do not always match the lofty goals enshrined in the Paris Accord, the noteworthy targets embodied in the Sustainable Development Goals, or the politically progressive ambitions stated in European climate pathways. The more we currently accelerate some low-carbon transitions, the more uneven development occurs and the more a degree of violence, misery and mayhem is also accelerated. There is a moral injunction to addressing one pressing environmental problem of climate change by aggravating other social and ecological problems related to disempowerment, inequality, poverty, and exploitation. But there is also the pragmatic concern of making such transitions self-defeating, for by harming those most vulnerable among us they will invariable lead to resistance and crises of legitimacy. It is no longer possible to hide from or disregard the induced vulnerabilities to which low-carbon transitions can contribute or exacerbate. Therefore, energy and climate planners need to harness more robust, and urgent, modes of accountability and action to better recognize and address them.

CRediT authorship contribution statement

Benjamin K. Sovacool: Project administration, Funding acquisition, Conceptualization, Methodology, Validation, Investigation. **Bruno Turnheim:** Conceptualization, Methodology, Validation, Investigation. **Andrew Hook:** . **Andrea Brock:** Conceptualization, Methodology, Validation, Investigation. **Mari Martiskainen:** Conceptualization, Methodology, Validation, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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